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The Noise of a Forward Swept Fan

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The Noise Reduction of a Forward Swept Fan

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Summary

A forward swept fan, designated the Quiet High Speed Fan (QHSF), was tested in the NASA Glenn 9- by 15-foot Low Speed Wind Tunnel to investigate its noise reduction relative to a baseline fan of the same aerodynamic performance. The objective of the Quiet High Speed Fan was a 6 decibel reduction in the Effective Perceived Noise relative to the baseline fan at the takeoff condition. The intent of the Quiet High Speed Fan design was to provide both a multiple pure tone noise reduction from the forward sweep of the fan rotor and a rotor-stator interaction blade passing tone noise reduction from a leaned stator. The tunnel noise data indicted that the Quiet High Speed Fan was quieter than the baseline fan for a significant portion of the operating line and was 6dB quieter near the takeoff condition. Although reductions in the multiple pure tones were observed, the vast majority of the EPNdB reduction was a result of the reduction in the blade passing tone and its harmonics. The baseline fan's blade passing tone was dominated by the rotor-strut interaction mechanism. The observed blade passing tone reduction could be the result of either the redesign of the Quiet High Speed Fan Rotor or the redesigned stator. The exact cause of this rotor-strut noise reduction, whether from the rotor or stator redesign, was not discernable from this experiment.

Introduction

The NASA Advanced Subsonic Technology program has an ongoing noise reduction element to provide the technology to meet increasingly restrictive airport noise regulations and anticipated noise standards. As part of this effort a forward swept fan was designed and constructed by Honeywell Engines and Systems for the purpose of reducing the noise of supersonic tip speed fans. This 22 inch diameter fan, designated the Quiet High Speed Fan (QHSF), was tested in the NASA Glenn 9- by 15-foot Low Speed Wind Tunnel to investigate its noise reduction characteristics. In addition, a model of an existing conventional fan was also tested to provide a noise baseline. The noise levels for the Quiet High Speed Fan and the baseline fan are presented in this report and the noise reductions achieved by the QHSF are evaluated.

Apparatus and Procedure

Baseline Fan

The baseline fan is a 22-inch model of the fan used on the Honeywell TFE731-60 engine. This fan consists of a damperless, moderately aft swept rotor and aft swept stator vanes. The baseline fan had considerable acoustic input in its original design. Blade /vane ratio, rotor-stator spacing and vane sweep were chosen to achieve minimum noise levels from this fan. A photograph of this baseline fan model is shown in figure 1(a) with the fan case removed so both the rotor and stator vanes are visible. A side view cross section of this fan is shown in figure 1(b). A listing of the design stage characteristics is shown in table I for this baseline fan. The design, takeoff, cutback and approach tip speeds are 1474, 1328, 1111 and 868 feet per second respectively.

Quiet High Speed Fan

The Quiet High Speed Fan was designed to have the same aerodynamic performance as that of the baseline fan (table I) but with reduced noise. The acoustic objective of the QHSF was a 6 decibel reduction in the effective perceived noise relative to the baseline fan at the takeoff condition. The noise reduction was planned to consist of reductions in multiple pure tone noise and rotor-stator interaction noise.

The multiple pure tone noise is generally attributed to pressure disturbances from the shock structure on the rotor blade. The QHSF incorporates forward sweep on the rotor to reduce the relative velocity component normal to the blade to subsonic levels. The intent of this sweep is to eliminate the formation of the inlet shock and achieve a multiple pure tone noise reduction. The goal of the rotor blade design was also to contain the remaining shock structure within the blade passages so the shocks would not propagate out the inlet. The forward swept rotor design was not able to achieve this goal at all radial positions at all fan speeds but the goal was achieved over a wide range of positions and speeds such that a significant reduction in multiple pure tone noise was predicted. A photograph of the QHSF is shown in figure 2(a) and a cross section in figure 2(b). The 50 degree forward sweep of the rotor is apparent in these figures.

A significant fan noise source results from the interaction of the rotor wake with the stator leading edge. If the trace speed of the rotor wake passing over the stator leading edge is supersonic, significant noise can be generated. To minimize the trace speed the fan should be designed so the wake intersects the stator leading edge as close to perpendicular as possible. The baseline fan stator vanes are aft swept but basically radial and had significant trace speeds. To minimize the trace speed and reduce the interaction noise, the QHSF stator vanes have been designed with lean in the opposite direction to the rotor wake. The amount of this lean increases near the outer shroud to a maximum of 30 degrees at the tip. The stator lean is visible in figures 2(a) and (b) and a photograph showing the magnitude of this lean at the stator tip is found in figure 2(c). This lean results in a near orthogonal intersection between the rotor wake and the stator vane leading edge in the outer span region. This reduces the wake trace speed and thus the predicted rotor-stator interaction noise. Reference 1 gives a more complete description of the Quiet High Speed Fan design and provides considerably more acoustic design detail.

Aerodynamic Operation

The drive rig was operated to obtain the same mass flow and pressure ratio for the baseline fan and the Quiet High Speed Fan at the acoustic test points along their design operating lines. The fans were also operated such as to obtain the same bypass ratio variation with speed as that obtained for the TFE 731-60 engine. This bypass ratio variation was achieved by having a simulated core flow that had its own variable area nozzle. This simulated core flow passage and the variable area nozzle can be seen in figures 1(b) and 2(b). A listing of the bypass ratio at the different tip speeds is seen in table II. A complete description of the fan operation and the aerodynamic results of the testing can be found in reference 2.

Acoustic Data

Acoustic data were obtained for both fans in the NASA Glenn 9- by 15-foot Low Speed Wind Tunnel. Two basic tunnel configurations were tested for each fan. In the first configuration the fans were tested in an open test section configuration as shown in the top view sketch of figure 3(a). Acoustic data were obtained with 3 fixed microphones and 1 traversing microphone. The tunnel was operated at a through flow Mach number of 0.1. A photograph of the QHSF in the test section is shown in figure 4. Here the traversing microphone is shown but the fixed microphones are not installed. The acoustic treatment is visible on the wall but a plastic grate, not used during the testing, covers the tunnel floor.

In the second configuration, a wall was erected from floor to ceiling in the tunnel to block the noise from the fan exit from reaching the forward traverse positions. This enabled the inlet noise to be measured without contamination from the aft noise. As seen in figure 3(b) the wall extended from a location even with the inlet nozzle lip to the end of the treated test section. The wall was located 6 inches from the fan nacelle. The fixed microphones were removed and only the traversing microphone was present for this tunnel configuration.

For the open tunnel configuration, the acoustic data were obtained by the traverse at 48 stops yielding emission angles from 24.6 to 135 degrees at the tunnel Mach number of 0.1 and by three fixed location microphones at emission angles of 136.4, 147.3 and 158.1 degrees. Only the traverse microphone was used with the acoustic wall configuration with the tunnel operating at Mach 0.1. Two narrowband spectra were taken at each survey location using 5.9 and 59 Hertz bandwidths. From these narrowband spectra a 1/3rd octave band spectra was also constructed. All of the noise data presented in this report are in 1 foot loss-less form at the emitted angles unless otherwise specifically noted.

In general the fans were tested at 15 different corrected tip speeds varying from 817 to 1474 ft/sec. The approach, cutback, takeoff and design tip speeds are 868, 1111, 1328, and 1474 ft/sec, respectively. Table III lists the tested conditions for the baseline fan and table IV lists the values for the QHSF. During the QHSF tests extraneous tones were present at some of the desired test conditions. With slight changes in tip speed or bypass ratio, these extraneous tones disappeared and the acoustic data were obtained at these slightly different test conditions. These different test points are indicated in table IV. The extraneous tones will be discussed later in the report.

Results and Discussion

Aerodynamic

The complete aerodynamic data taken on the baseline and Quiet High Speed Fans are found in reference 2. An overall performance comparison between the two fans during the acoustic testing can be seen in figure 5. Here the stage pressure ratio versus weight flow operating lines are seen for the two fans. Very little difference is seen between the acoustic test points for the two fans. The maximum difference appears to be at the highest weight flow condition where a difference of approximately 4 percent is observed. Assuming a 4 percent difference in pressure rise at the same weight flow translates into a 4 percent difference in thrust and approximating the noise difference using 10 Log thrust ratio, the predicted noise difference would be less than 0.2 decibels. Since this 0.2 decibels is within the previously observed variability of the noise data, there is no need to correct the data for the slight difference in performance of the two fans and direct comparison of the measured noise levels between the two fans is then possible.

The QHSF did exhibit off-operating line performance that was different than the baseline fan. In particular, the QHSF exhibited a significantly smaller operating range than the baseline fan because of a flutter condition on the stall side of the operating line. This would limit the ability of the QHSF to be used on an actual engine and is the subject of more detailed discussion in reference 2. Since acoustic data were only taken on the operating line where the two fans had similar performance, the direct noise comparison between the two fans is valid.

Acoustic Results

Effective Perceived Noise Levels.—As indicated previously, the acoustic objective of the Quiet High Speed Fan design was a 6 decibel reduction in Effective Perceived Noise Level (EPNL) relative to the baseline fan at the takeoff condition. To evaluate the success of the QHSF, the EPNLs of the two fans were calculated for single fan level flyovers at 1500 feet from the data taken without the barrier wall in the tunnel. These levels were calculated for a 30.7 inch diameter fan, the size that would be included in the TFE 731-60 engine. Since the data were obtained on a 22 inch diameter fan this represents a scale factor of 1.395.

The results of these EPNL calculations are shown in figure 6. Here the EPNLs are plotted versus the corrected tip speed. At the lower tip speeds, below 1100 ft/sec, the QHSF is slightly noisier than the baseline fan. At slightly above 1100 ft/sec the two fans reach the same noise levels. At higher tip speeds, the noise of the baseline fan continues to rise but the QHSF reduces in noise level beyond 1200 ft/sec and doesn’t start to rise again until 1383 ft/sec. The curves then eventually reach close to the same noise level at 1474 ft/sec. This leaves a large region from 1200 ft/sec to 1474 ft/sec where the QHSF is significantly quieter than the baseline fan. The Quiet High Speed Fan is 5.3 EPNdB quieter at 1328 ft/sec, the takeoff condition and 6.86 EPNdB quieter at 1392 ft/sec. These noise reductions basically verify the design objective of the Quiet High Speed Fan and validate the noise reduction ideas incorporated in the QHSF.

Since this technology might be applied to larger fans than the 30.7 inch diameter TFE 731-60 engine, EPNdB calculations were made for single fan flyovers of larger fans. Figure 7 is a plot of the takeoff (1328 ft/sec tip speed) EPNdB for fans with various scale factors up to 8 (176 inch diameter fan). As can be seen from this figure, the noise advantage of the QHSF is

significant at all of the scale factors investigated. This indicates that this technology would be applicable to larger fans than that for the TFE 731-60 engine.

Narrowband Spectra.—Some 0-8KHz narrowband spectra are presented in figures 8 thru 10 in order to investigate the source of the EPNL noise reduction.. These data are at the tip speed where the maximum noise reduction occurred, 1392 ft/sec. and represent 45.6, 90, and 136.4 degree angles, respectively. Comparing the fans at the forward angle, 45.6 degrees, the reduction in multiple pure tones, MPTs, is apparent. This MPT reduction is particularly apparent below 200 Hz and between 6000 and 7000 Hz. These MPT reductions indicate that the forward swept QHSF rotor was successful in controlling the shock structure that forms the multiple pure tones. The blade passing tone at 5400 Hz has also been reduced with the QHSF at these forward angles. Some broadband noise reduction is also seen at the higher frequencies on this figure.

At 90 degrees, figure 9, a small amount of multiple pure tone activity is present for the baseline fan and the activity has been reduced with the QHSF. The major reduction at this angle is at the blade passing tone. This blade passing tone dominates the baseline spectra and has significantly been reduced in the QHSF spectra.

The same dominance of the blade passing tone is seen at the 136.4 degree angle, figure 10. Again this level is reduced significantly with the QHSF. In comparing the levels of the baseline fan blade passing tone at the aft angles with the multiple pure tones at the forward angles, it would appear that the blade passing tone is controlling the EPNLs. In comparing the baseline blade passing tone in the aft, figure 10, with that in the front, figure 8, the aft tone is some 20 decibels louder. A plot of blade passing tone versus angle is shown in figure 11. Again, the aft dominance is apparent with the peak aft tone being significantly louder than the inlet.

Since the blade passing tone would likely dominate the effective perceived noise levels, and the highest noise reductions with the QHSF are at the blade passing tone, the EPNL reductions for the QHSF are most likely from the reduction in the blade passing tone as opposed to multiple pure tone reductions.

Sound Power Levels.—To further investigate the role of blade passing tone reductions in the observed EPNL reduction, the 0 to 8K total sound power levels of the two fans are presented in figure 12. As can be seen, multiple pure tones are visible in the baseline spectra but the blade passing tone is the dominant feature. The QHSF spectra show reductions in the multiple pure tones and the blade passing tone. Again with the dominance of the blade passing in the baseline fans power level spectra, the reduction in EPNL is primarily the result of the QHSF having a lower blade passing tone.

Since the Effective Perceived Noise Levels are based on the 1/3rd octave spectra, the total 1/3rd octave power levels are presented in figure 13. The dominance of the blade passing tone and its harmonics for the baseline fan is even more apparent on a 1/3rd octave basis. Although there is some reduction in the broadband noise at higher frequency, the reduction in the blade passing tone and its harmonics are the primary benefit of the QHSF. Although these 1/3rd octave plots are for the 22 inch fan data, the slight shift to lower frequencies for the 1.395 scale, 30.7 inch, fan would not change the conclusion that the EPNL differences shown in figure 6 are the result of reductions in the blade passing tones and its harmonics.

To further illustrate this point, a calculation was made for the EPNLs of the two fans at the 1392 ft/sec tip speed with the blade passing tone and its harmonics removed. In this case, with the tones removed, the base fan had an EPNL of 87.3 and the QHSF had a level of 86.5.

These compare with 94.7 and 87.9 for the data of figure 6 where the blade passing tone was present. In addition to having much lower levels with the tones removed, the difference in Effective Perceived Noise Level between the two fans is only 0.8 dB where as the difference with the blade passing tone present is 6.8 dB This further verifies that the noise reduction of the QHSF is the result of reduced blade passing noise.

Internal mode measurements in the inlet and exhaust ducts of the baseline fan, reference 3, indicated that the blade passing tone is generated by the rotor-strut interaction. This interaction could either be the result of the rotor wake-strut mechanism or the strut potential field interacting with the rotor. The observed blade passing tone noise reduction of the QHSF may result from a number of different changes in the QHSF design from that of the baseline fan. The forward sweep of the rotor would increase the spacing between the rotor and the strut thereby reducing both the wake strength that would impact the strut and the strut potential field that would be encountered by the rotor. The QHSF rotor also has roughly 25 percent less loading at the tip resulting in smaller wakes that would lower the wake-strut interaction noise. A reduction in rotor tip wakes has been shown previously to reduce rotor-stator interaction noise (ref. 4) and a reduction in rotor-strut noise would be a logical extension. The QHSF stator was specifically leaned at the tip to reduce rotor wake–stator interaction noise but this stator redesign would also change the wake structure that would impact the downstream struts. The exact cause of the tone noise reduction, rotor or stator redesign, is not discernable from this experiment but these results suggest that a future experiment with an un-leaned stator might help to separate the sources.

Low Speed Noise Increase.—While significant noise reductions were achieved with the Quiet High Speed Fan near the takeoff condition, some small noise increases were observed at low tip speeds for this fan (fig. 6). To investigate the noise increase, the data at a subsonic tip speed, 913 ft/sec were examined. Figure 14 shows the total sound power for the baseline and Quiet High Speed fans. As can be observed, the blade passing tone and twice blade passing tone are reduced with the QHSF. The broadband noise however has increased with the QHSF. This increase in the range from 500 to 5000 hertz is overbalancing the tone noise reduction and results in an EPNL increase for the QHSF at the lower tip speeds. The reason for this increase is not known but may be related to off design performance of the severely leaned stator tips or separated flow at the stator hub.

Extra Tones.—As mentioned previously, extraneous tones at specific conditions dominated the Quiet High Speed Fan spectra. Because of the severity of the tones and concern for the mechanical integrity of the fan, it was not possible to remain on those conditions long enough to obtain a complete noise traverse. Therefore data were only taken with the traverse in one position, 56.4 degrees. The spectra for the three fan speeds of 1037, 1063, and 1152 ft/sec are shown in figure 15. The 1063 and 1152 ft/sec tip speeds were desired acoustic test points. Slight changes in tip speed or bypass ratio resulted in the disappearance of these tones and the full traverse noise data were obtained at these slightly different conditions as indicated in table IV. The reason for these tones has not been identified but speculations about stator or fan duct resonances and core nozzle instabilities were advanced.

Data with Acoustic Barrier Wall.—Data were obtained on both the baseline and Quiet High Speed fans with an acoustic barrier wall blocking the noise from the fan exhaust from reaching the forward portions of the microphone traverse. The wall extends from floor to ceiling in the test section and has its leading edge in the same axial plane as the fan inlet lip (fig. 3(b)).

To quantify the portion of noise measured in the forward arc, which emanated from the exhaust, the sound power level from the 83-degree emitted angle (furthest aft ray not blocked by the wall) and forward was calculated for the base and Quiet High Speed fans with and without the acoustic wall. Figure 16 shows the baseline fan data and figure 17 the Quiet High Speed Fan data for the 1392 ft/sec tip speed case. Upon comparing the sound power level data, with and without the wall (figs. 16 and 17), it can be seen that a significant reduction in broadband noise is observed with the wall present for both fans. This indicates that the broadband noise emanating from the fan exhaust is controlling the broadband level in the forward arc.

The removal of the aft broadband noise allows the multiple pure tone noise to be more readily observed (figs. 16(b) and 17(b)). By comparing the data with the wall present for the baseline fan, figure 16(b), and the QHSF, figure 17(b), the effect of the forward swept QHSF on multiple pure tone noise can be better observed and shows more of the reduction from the forward swept rotor. The barrier results, however, do not change the conclusion that the EPNL of the baseline fan is controlled by the blade passing tone and its harmonics nor does it change the conclusion that the noise reduction of the QHSF is primarily from the reduction in the blade passing tones.

In comparing the wall and no wall data, a reduction in the blade passing tone level is also observed. The blade passing tone directivities are shown for the baseline fan in figure 18 and for the QHSF in figure 19. For the baseline fan the wall appears to reduce the blade passing tone as far forward as 35 degrees. For the QHSF, the wall reduces the tone level as far forward as 55 degrees. This indicates that the blade passing tone is stronger toward the aft, and, along with the broadband noise result, illustrates the aft noise dominance of these fans.

Concluding Remarks

A forward swept fan, designed and constructed by Honeywell Engines and Systems, was tested in the NASA Glenn 9- by 15-foot Low Speed Wind Tunnel to investigate its noise reduction characteristics. The objective of this fan, designated the Quiet High Speed Fan (QHSF), was a 6 decibel reduction in the effective perceived noise relative to the fan used on the Honeywell TFE731-60 engine at the takeoff condition. The intent of the design was to provide both a multiple pure tone noise reduction from the forward sweep of the fan rotor and a rotor-stator interaction blade passing tone noise reduction from a leaned stator.

The Quiet High Speed Fan and a model of the Honeywell TFE731-60 fan, designated the baseline fan, were tested in 22 inch diameter size in two tunnel configurations; first with an open test section and then with a barrier wall which blocked the aft fan noise reaching the forward arc. The open tunnel data indicated that the QHSF was quieter than the baseline fan for a significant portion of the operating line and was 6 dB quieter near the takeoff condition. Although reductions in the multiple pure tones were observed, the vast majority of the EPNdB reduction was a result of the reduction of the blade passing tone and its harmonics. Internal mode measurements in the inlet and exhaust ducts of the baseline fan, reference 3, indicated that the blade passing tone is generated by the rotor-strut interaction. This interaction could either be the

result of the rotor wake-strut mechanism or the strut potential field interacting with the rotor. The observed blade passing tone noise reduction of the QHSF may result from a number of different changes in the QHSF design from that of the baseline fan. The forward sweep of the rotor would increase the spacing between the rotor and the strut thereby reducing both the wake strength that would impact the strut and the strut potential field that would be encountered by the rotor. The QHSF rotor also has roughly 25 percent less loading at the tip resulting in smaller wakes that would lower the wake-strut interaction noise. The QHSF stator was specifically leaned at the tip to reduce rotor wake–stator interaction noise but this stator redesign would also change the wake structure that would impact the downstream struts. The exact cause of the tone noise reduction, rotor or stator redesign is not discernable from this experiment but these results suggest that a future experiment with an un-leaned stator might help to separate the sources.

The data with the barrier wall present showed a significant reduction in the forward arc broadband noise levels, indicating that the fan exhaust broadband noise is controlling the forward arc broadband noise levels. This reduction in the forward arc broadband noise allowed the effect of the QHSF in reducing the multiple pure tone noise to be more readily observed. The barrier results do not, however, change the conclusion that the EPNL noise reduction of the QHSF is primarily from the reduction in the blade passing tone and its harmonics.

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3. Heidelberg, Laurence, Comparison of Tone Mode Measurements for a Forward Swept and Baseline Rotor Fan, AIAA–2003–3293.
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Table I.—Fan design parameters at fan aero design point for 22 inch diameter fan (baseline and QHSF)

Parameter	Value
Corrected weight flow, lbm/sec	98.9
Corrected weight flow per area, lbm/sec/ft^2	42.7
Tip speed, ft/sec	1474
Bypass ratio	3.83
Overall pressure ratio	1.82
Adiabatic efficiency, overall	0.895
Hub/tip ratio	0.35
Rotor blade count	22
Stator vane count	52

Table II.—Bypass ratio distribution with tip speed

Fan corrected tip speed, ft/sec	Bypass ratio
817	6.44
868 (approach)	6.24
913	6.05
960	5.83
1022	5.53
1063	5.34
1111 (cutback)	5.11
1152	4.92
1200	4.71
1248	4.51
1281	4.39
1328 (takeoff)	4.22
1392	4.03
1440	3.91
1474 (design)	3.83

Table III.—Baseline fan test points

Fan corrected rpm	Fan corrected tip speed, ft/sec
8516	817
9039	868
9510	913
10000	960
10646	1022
11071	1063
11572	1111
12000	1152
12500	1200
13000	1248
13342	1281
13831	1328
14500	1392
15000	1440
15357	1474

Table IV.—QHSF test points

Fan corrected rpm	Fan corrected tip speed, ft/sec
8516	817
9039	868
9510	913
10000	960
10646	1022
11150[a]	1070
11572	1111
12100[b]	1161
12500	1200
13000	1248
13342	1281
13831	1328
14500	1392
15000	1440
15357	1474

[a] Extraneous tones required an increase in tip speed.
[b] Extraneous tones required an increase in tip speed and a decrease in bypass ratio to 4.42 for the no wall configuration. No data were obtained with the wall present.

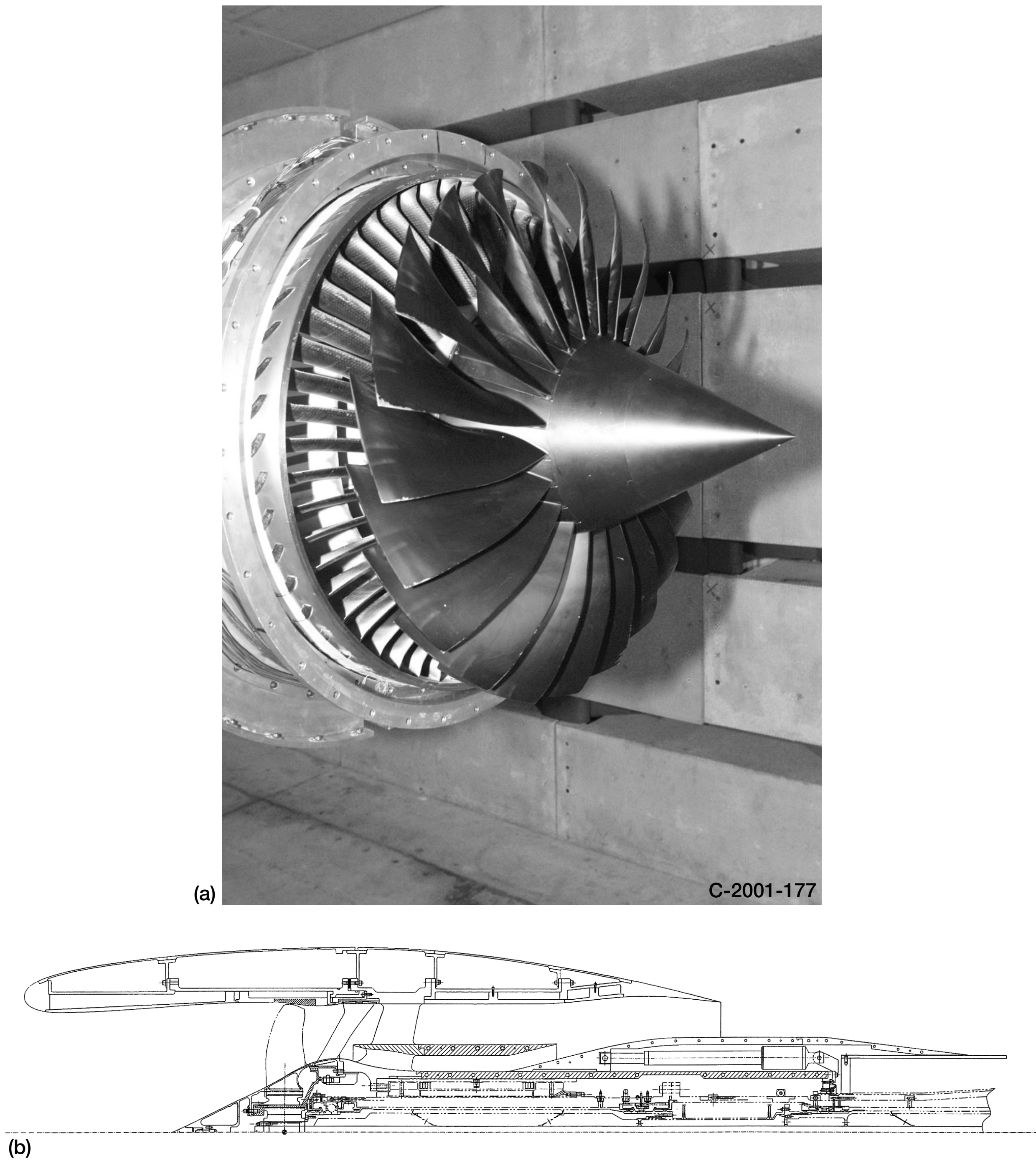

Figure 1.—Baseline fan. (a) Photograph. (b) Cross section.

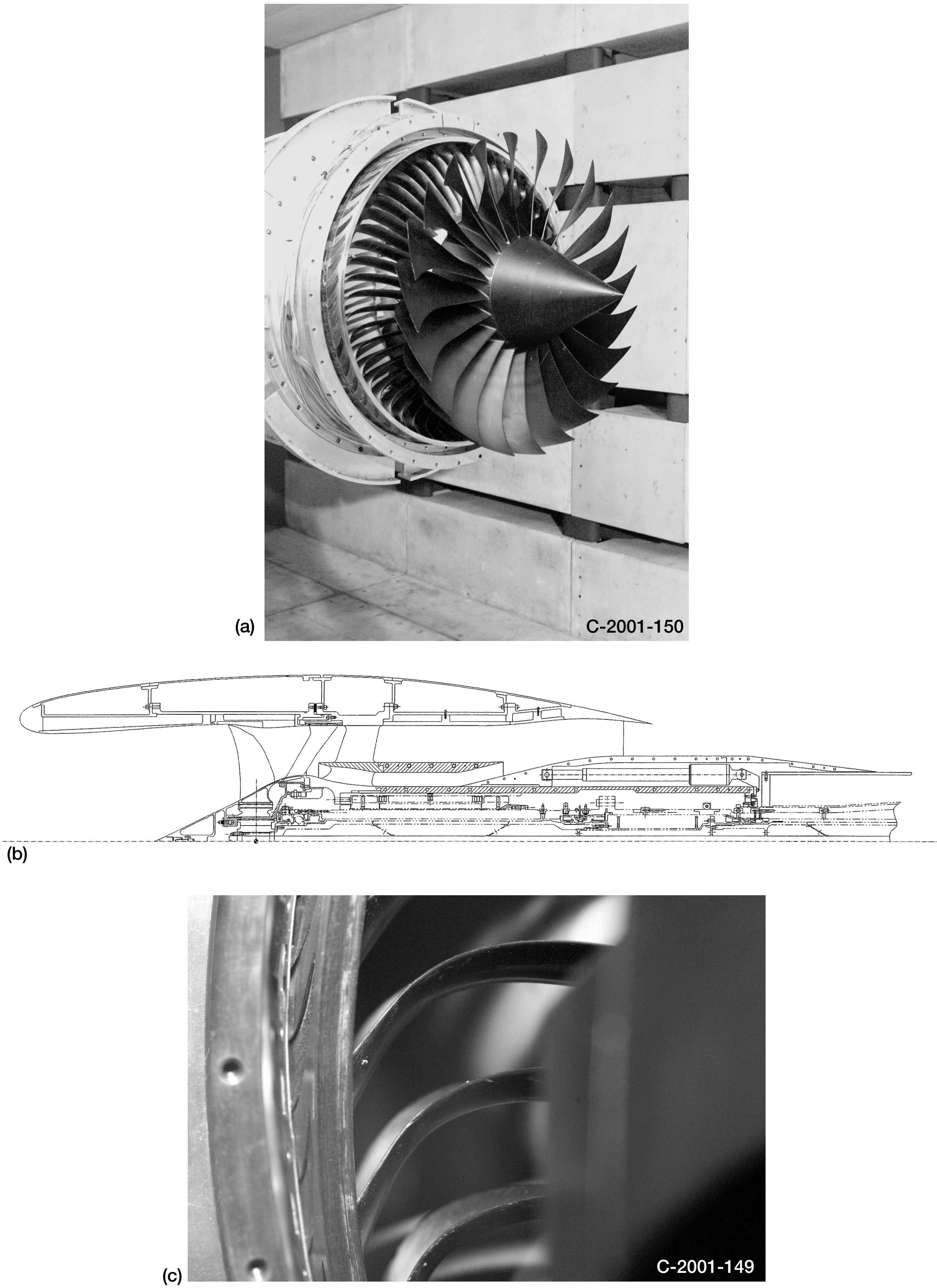

Figure 2.—Quiet high-speed fan. (a) Photograph. (b) Cross section. (c) Stator tip photograph.

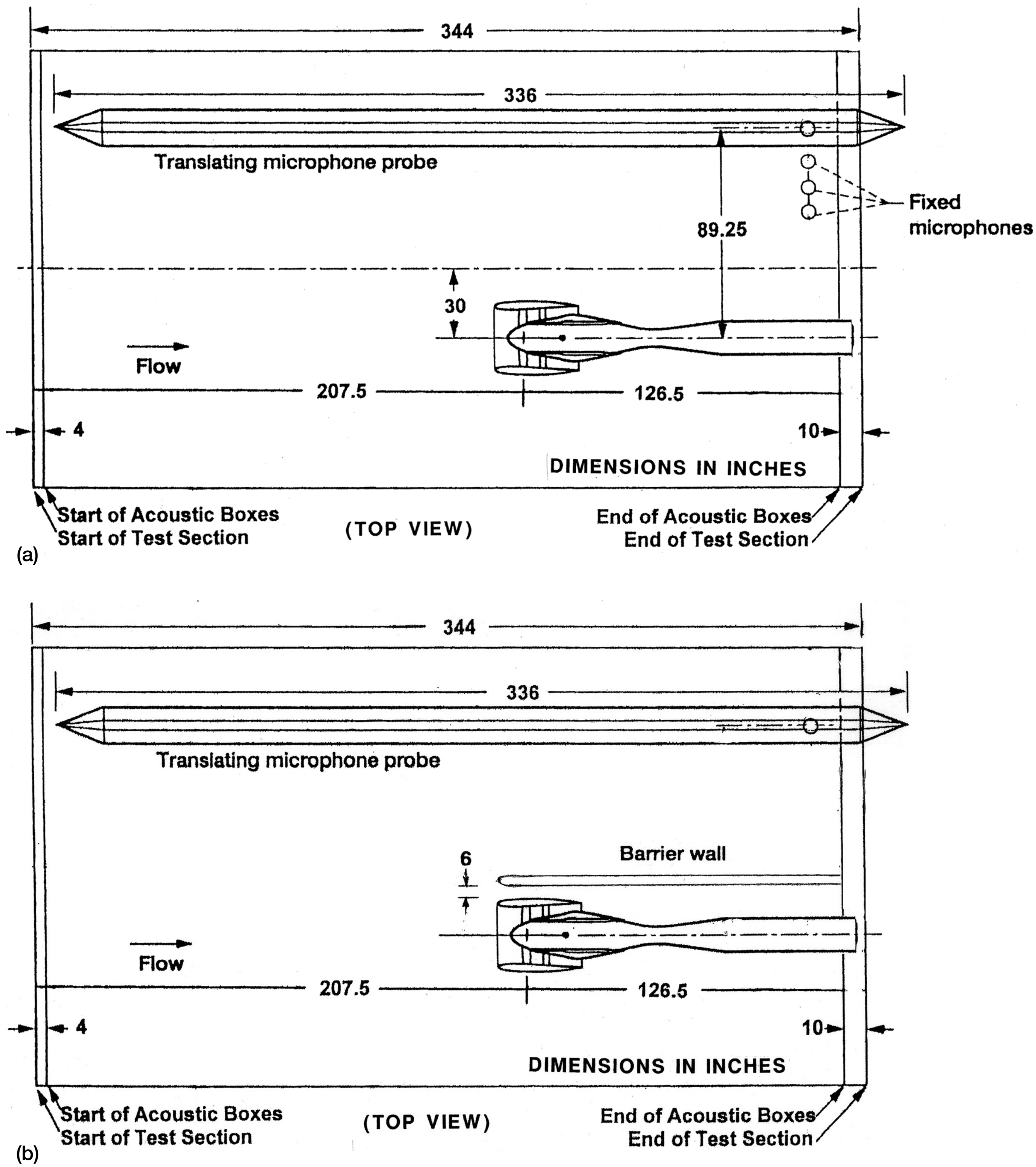

Figure 3.—Tunnel configurations. (a) Open test section (without wall). (b) Acoustic barrier wall.

Figure 4.—Quiet high speed fan in test section.

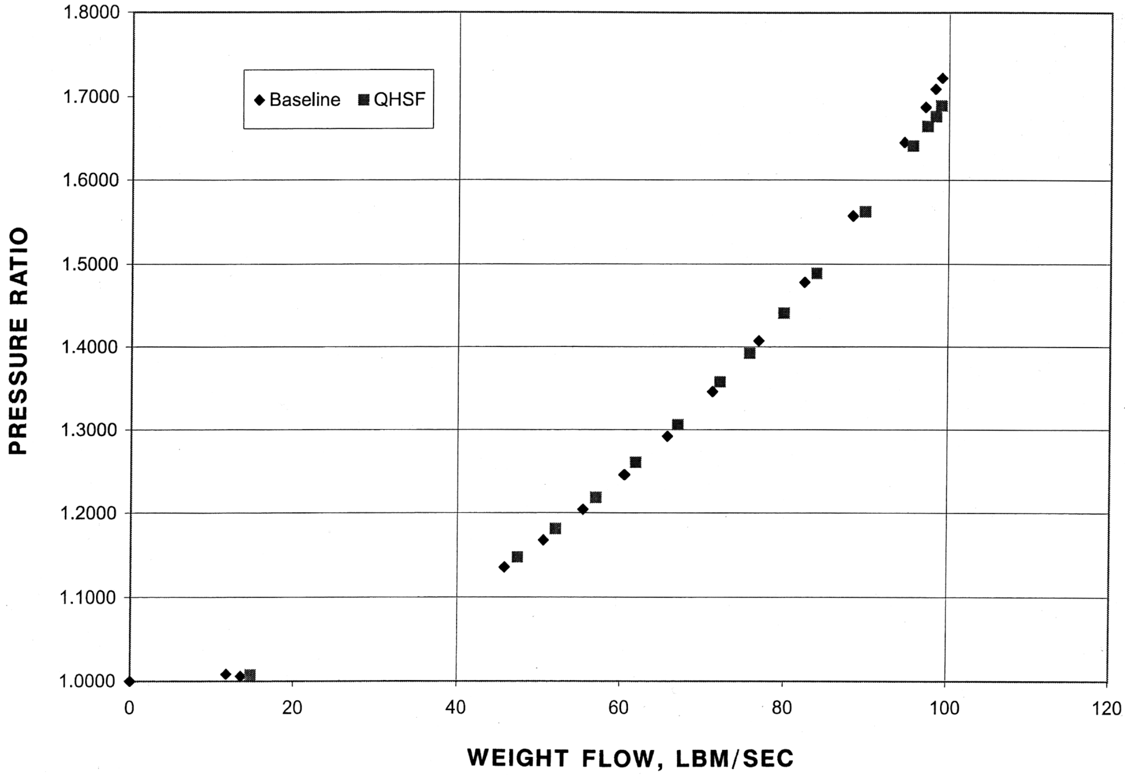

Figure 5.—Fan stage operating line comparison.

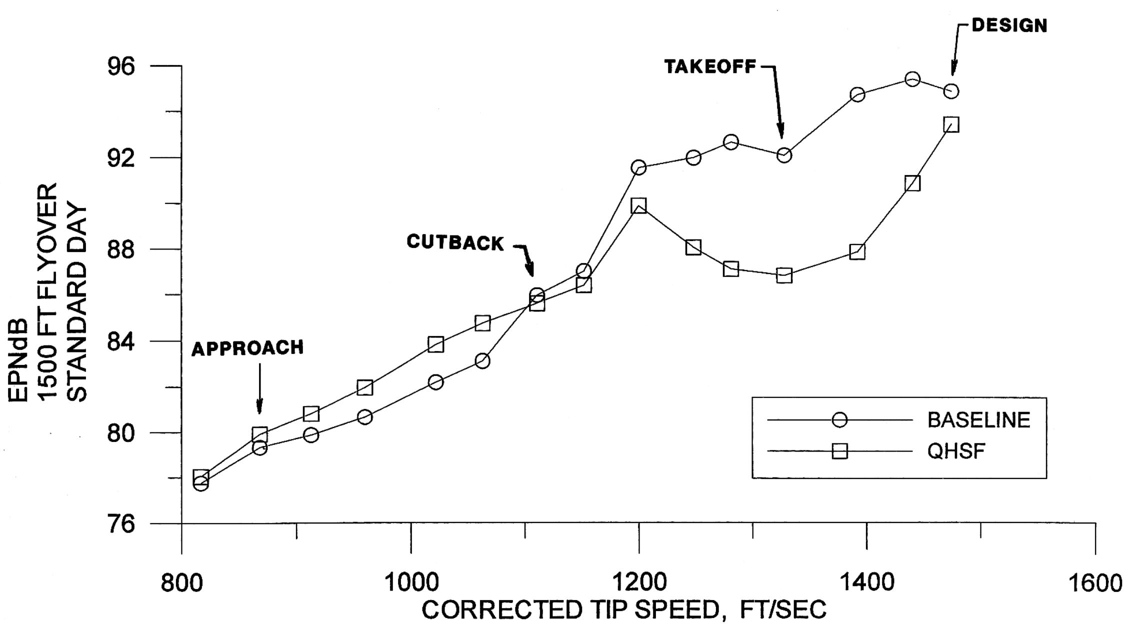

Figure 6.—EPNdB Variation with speed for a 30.7 inch diameter fan.

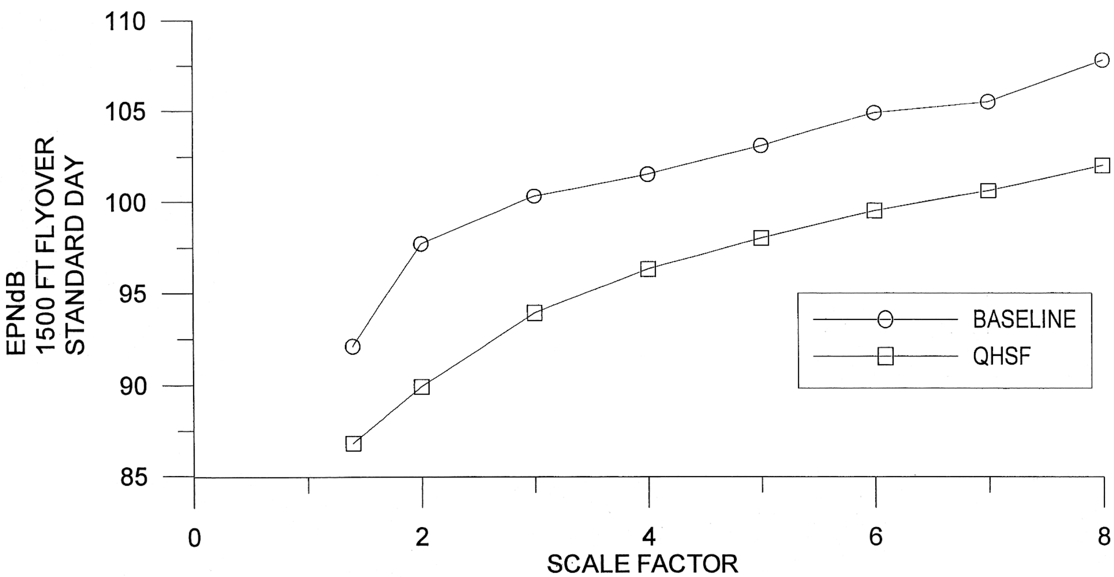

Figure 7.—EPNdB Variation with scale factor at the takeoff condition.

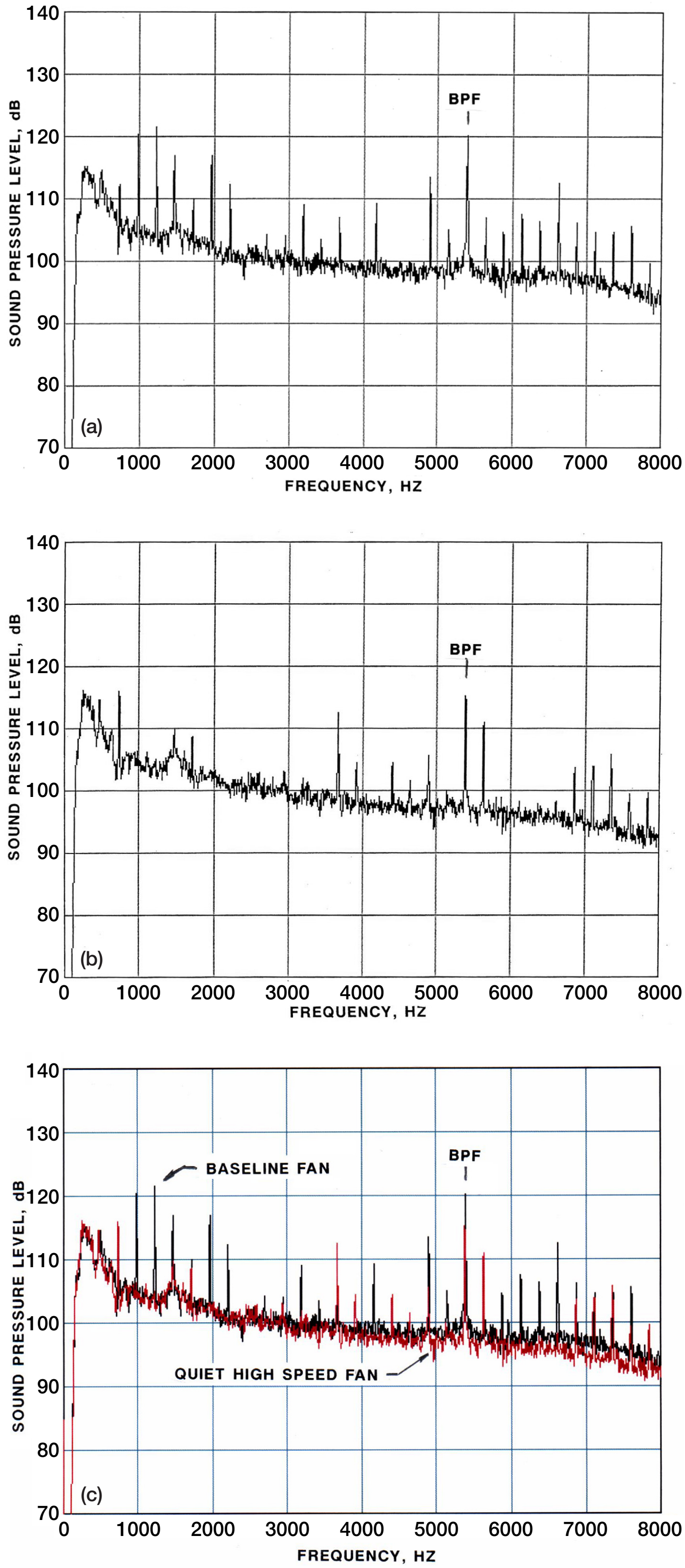

Figure 8.—Spectra at 45.6 degrees, 1392 ft/sec tip speed. (a) Baseline fan. (b) Quiet high-speed fan. (c) Composite.

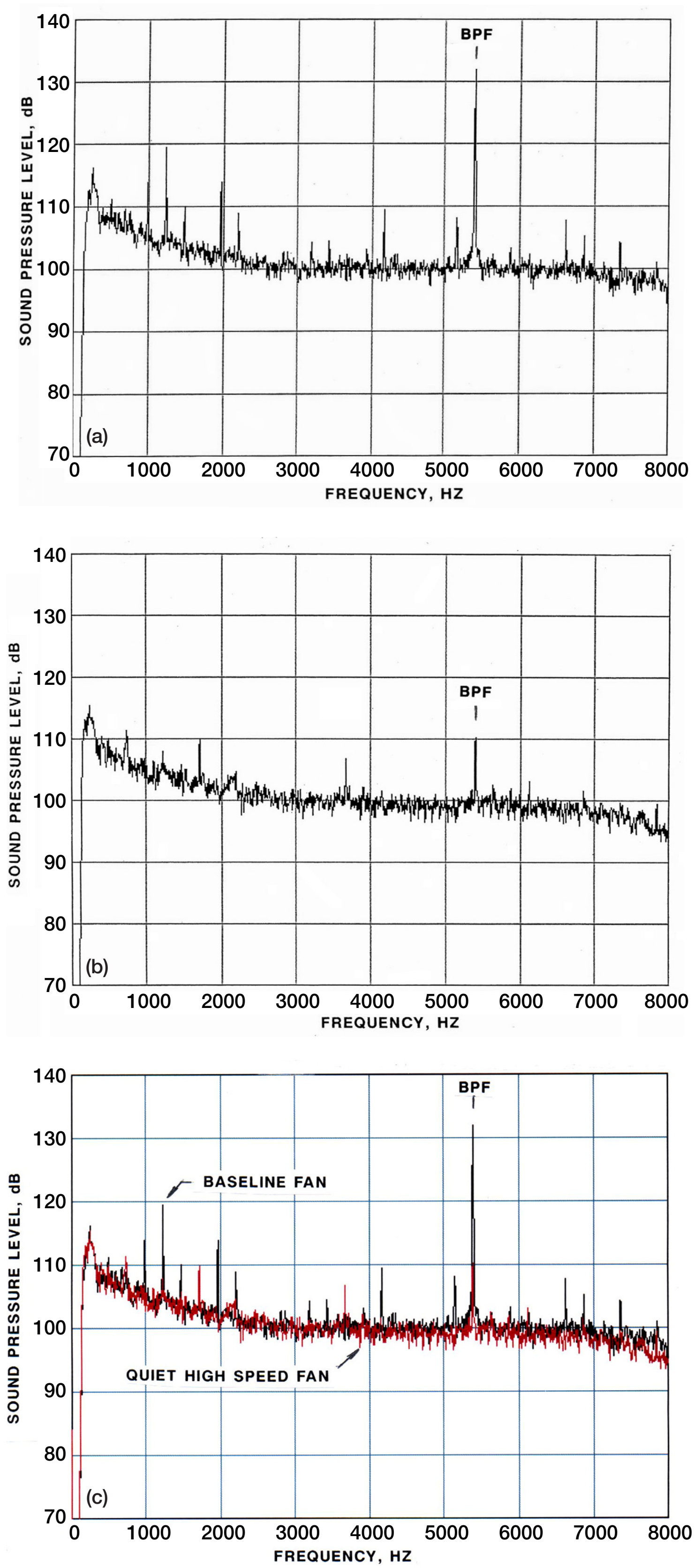

Figure 9.—Spectra at 90 degrees, 1392 ft/sec tip speed. (a) Baseline fan. (b) Quiet high-speed fan. (c) Composite.

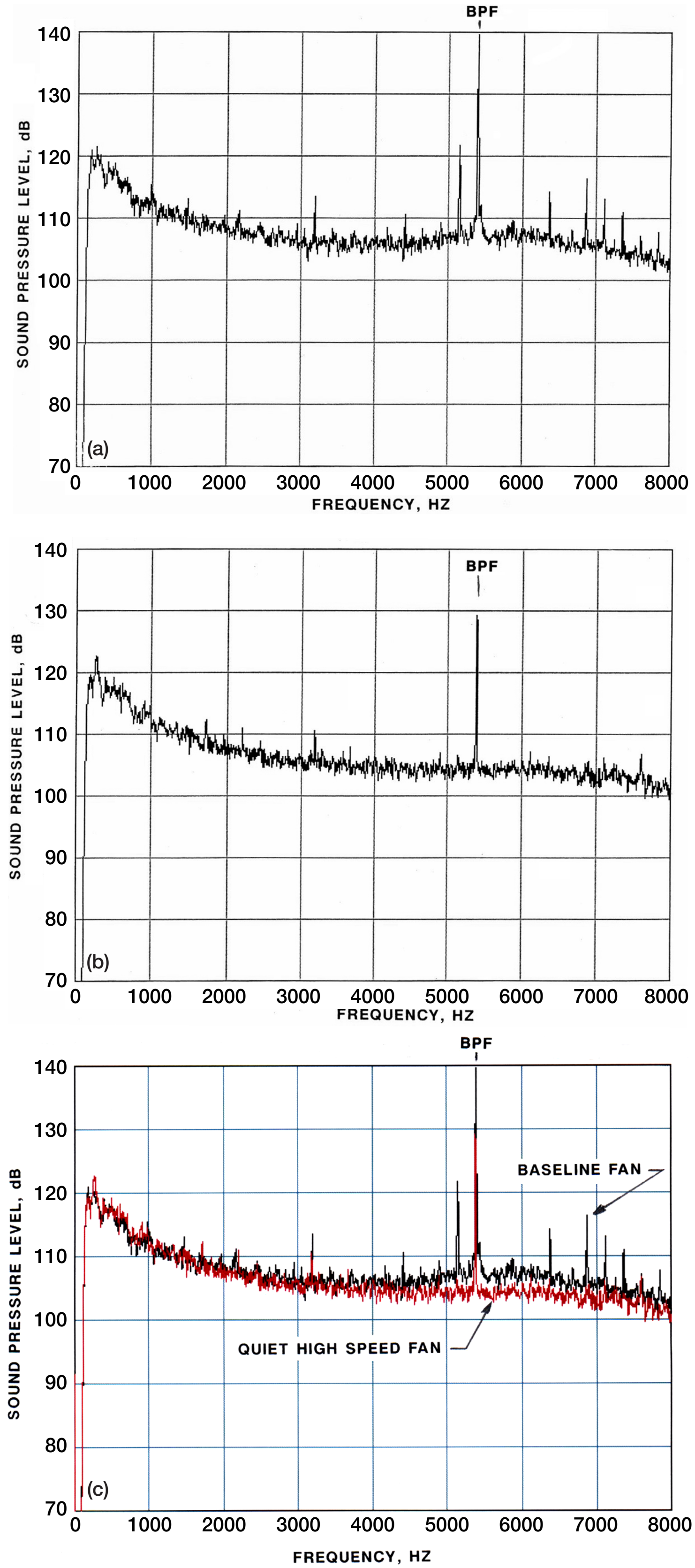

Figure 10.—Spectra at 136.4 degrees, 1392 ft/sec tip speed. (a) Baseline fan. (b) Quiet high-speed fan. (c) Composite.

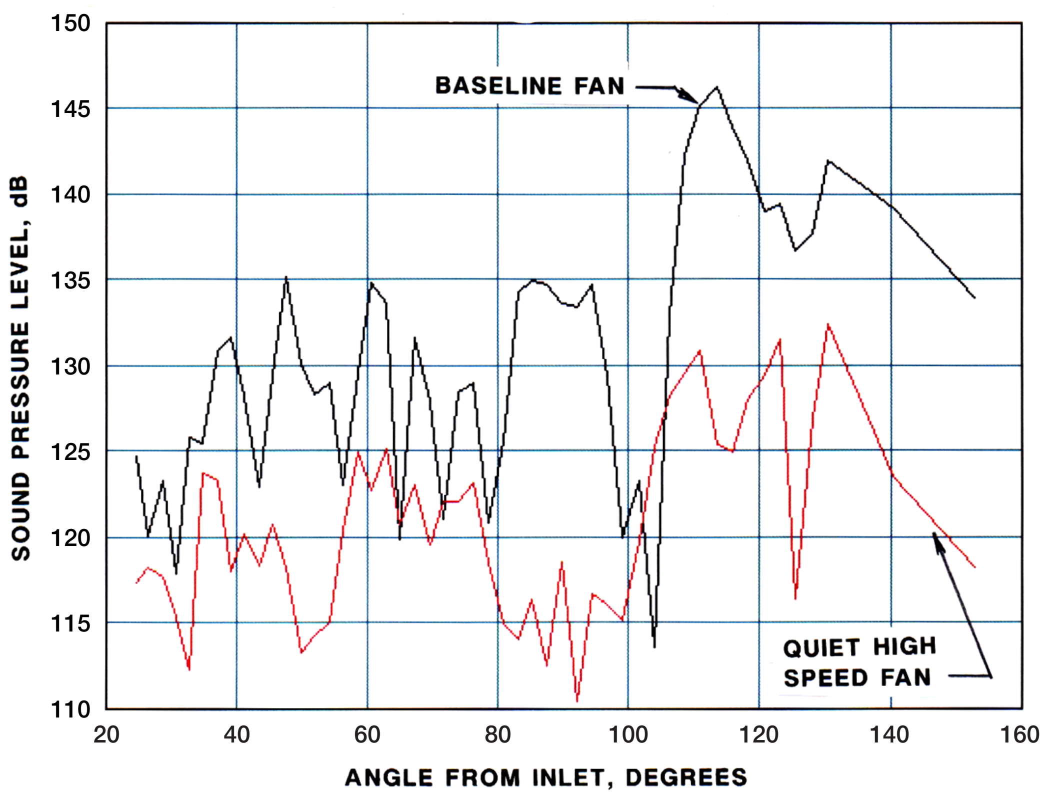

Figure 11.—Blade passing tone directivity at 1392 ft/sec tip speed.

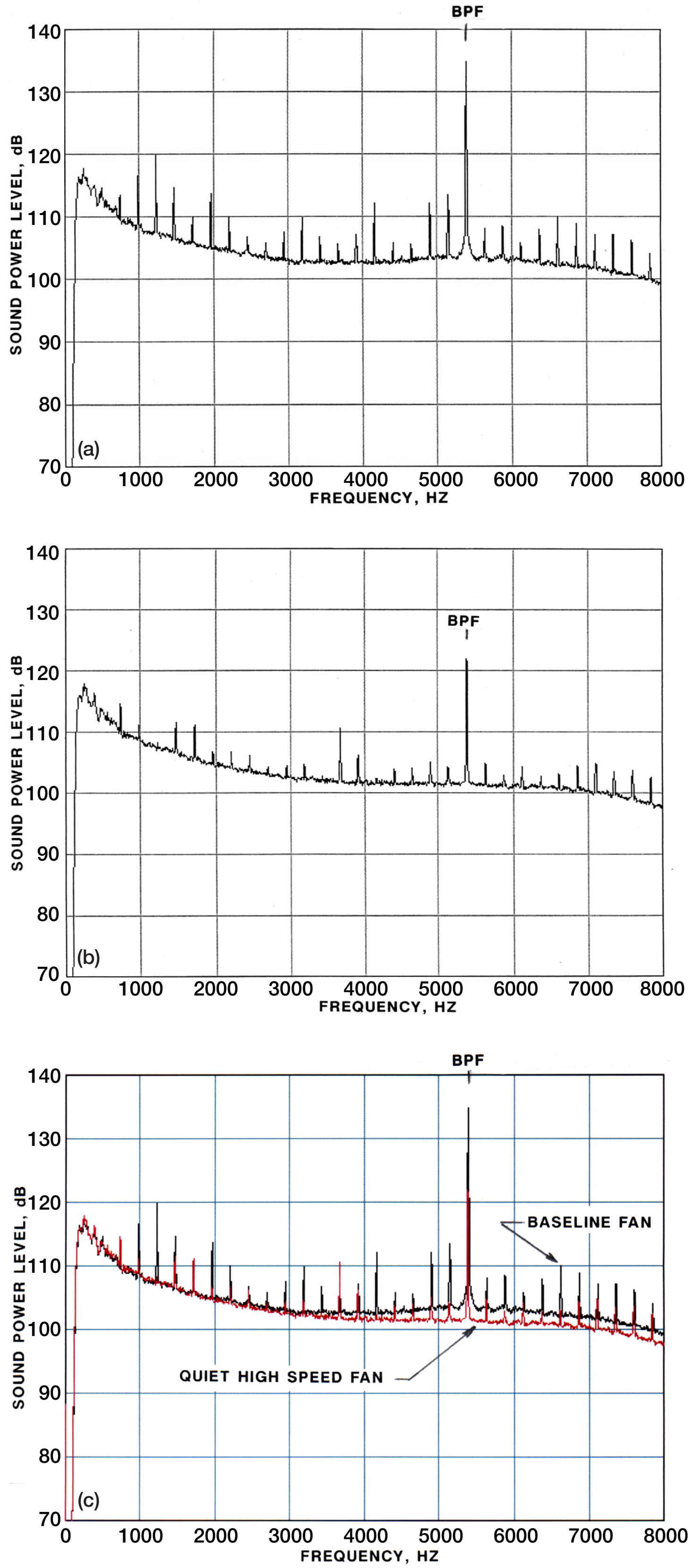

Figure 12.—Total sound power lever at 1392 ft/sec tip speed. (a) Baseline fan. (b) Quiet high-speed fan. (c) Composite.

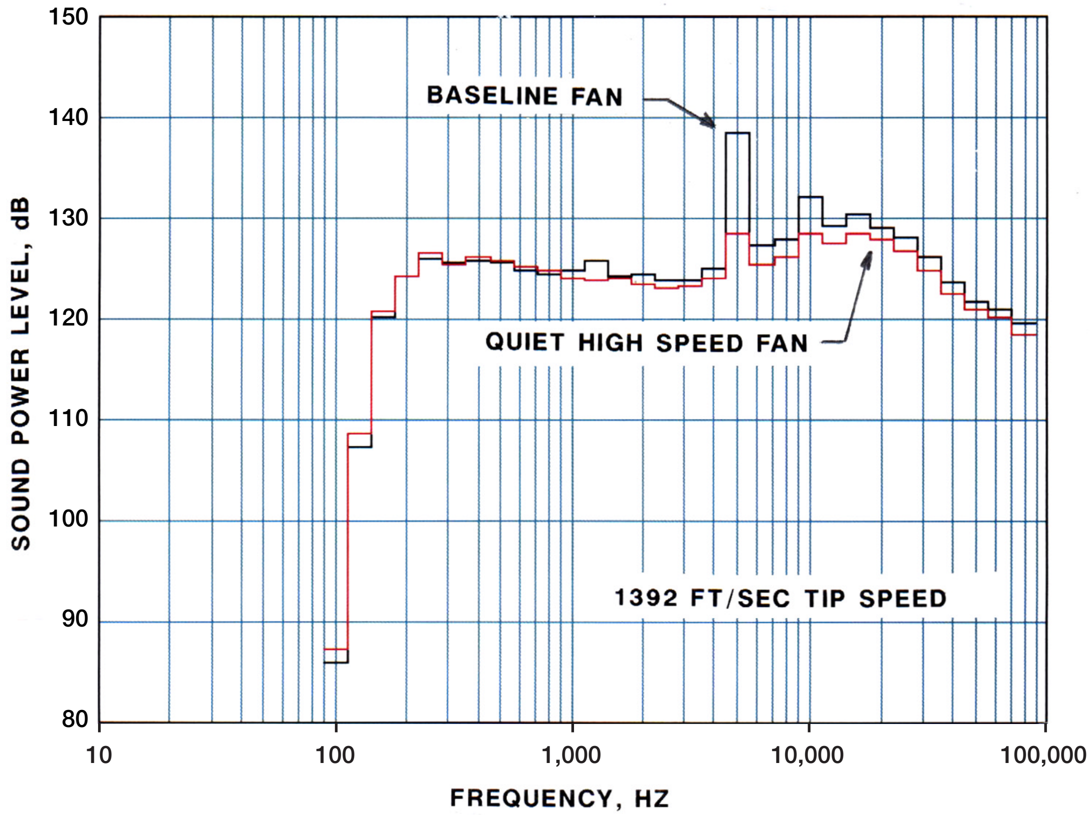

Figure 13.—One third octave total sound power level.

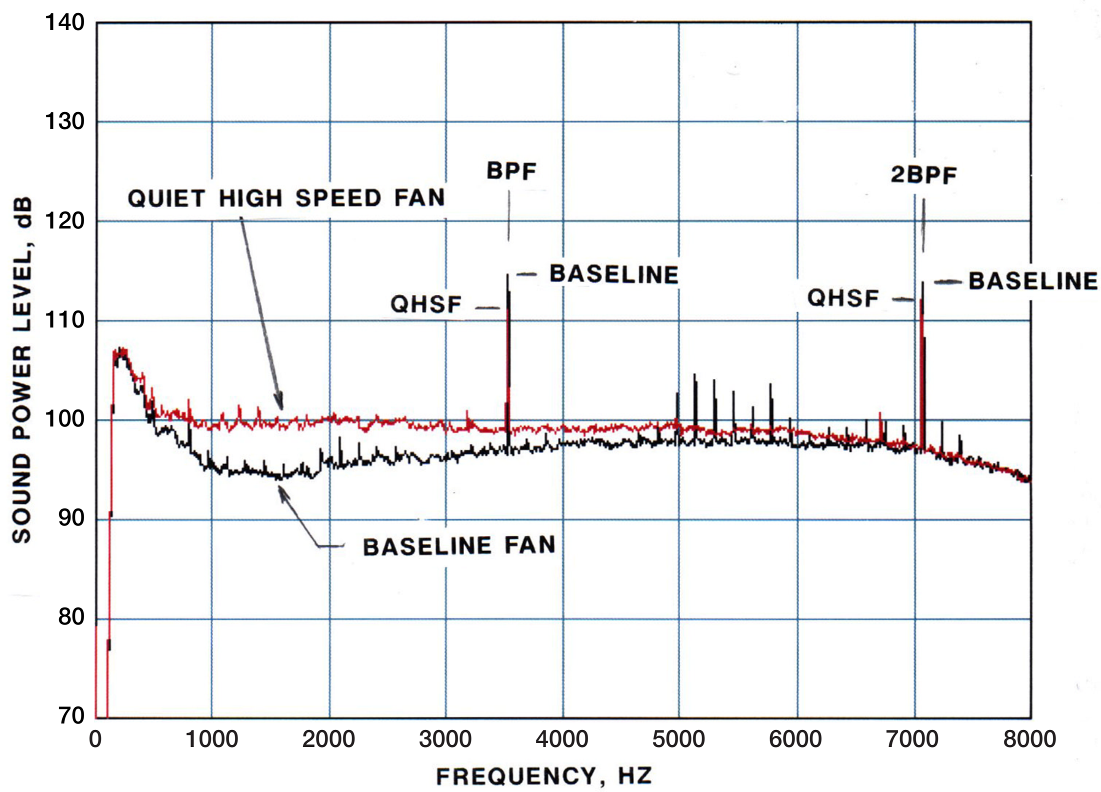

Figure 14.—Total sound power level at 913 ft/sec tip speed.

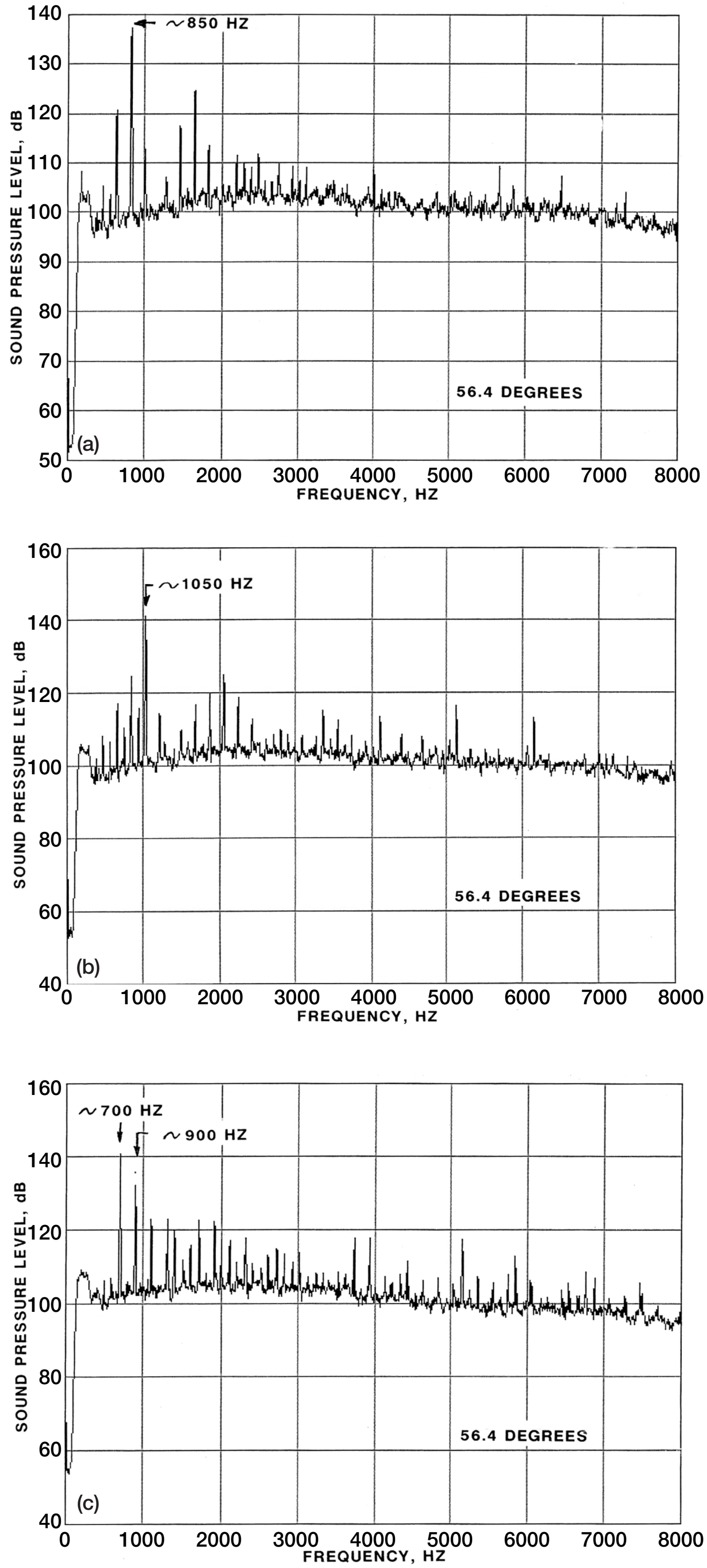

Figure 15.—Extraneous tones. (a) 1037 ft/sec tip speed. (b) 1063 ft/sec tip speed. (c) 1152 ft/sec tip speed.

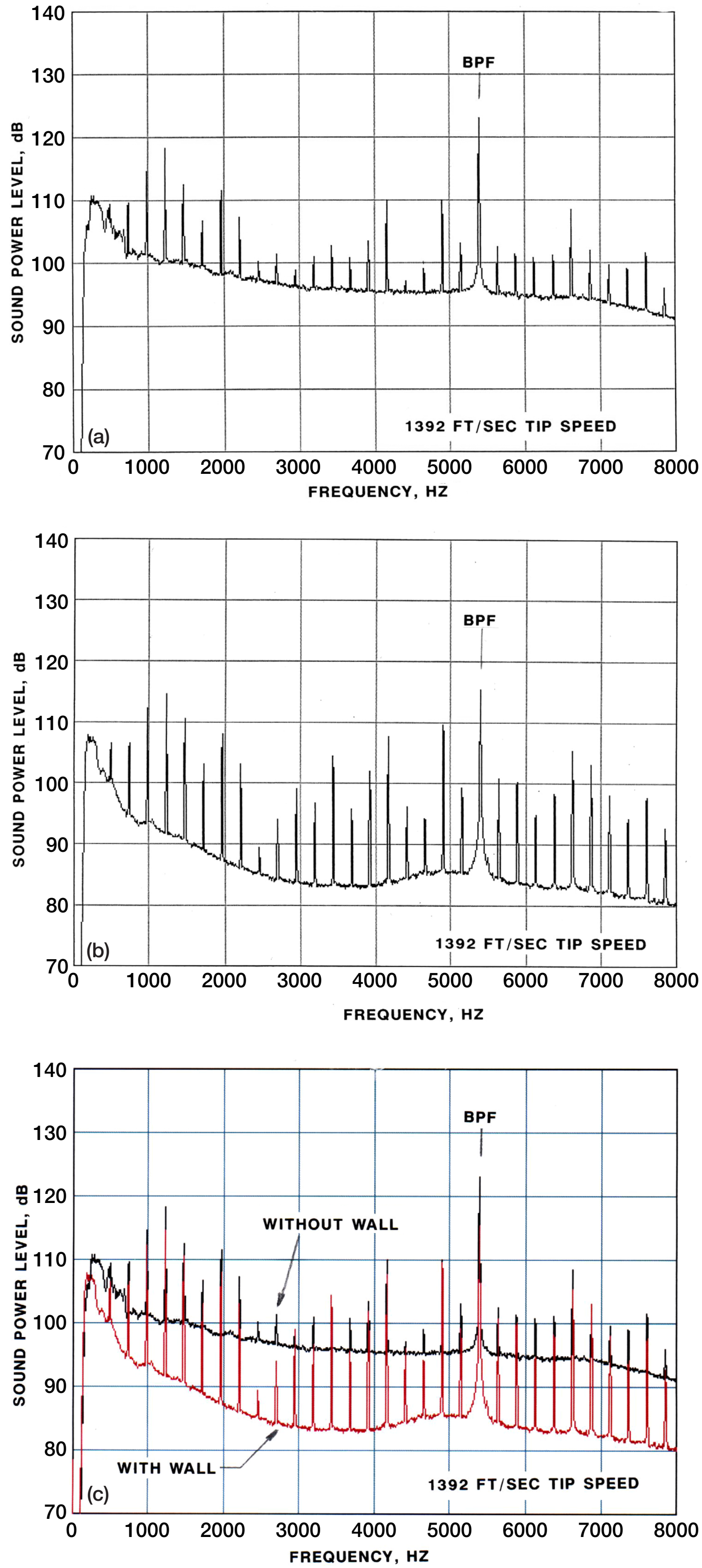

Figure 16.—Sound power lever for 83 degrees and forward. Baseline fan (a) without wall, (b) with wall, and (c) composite.

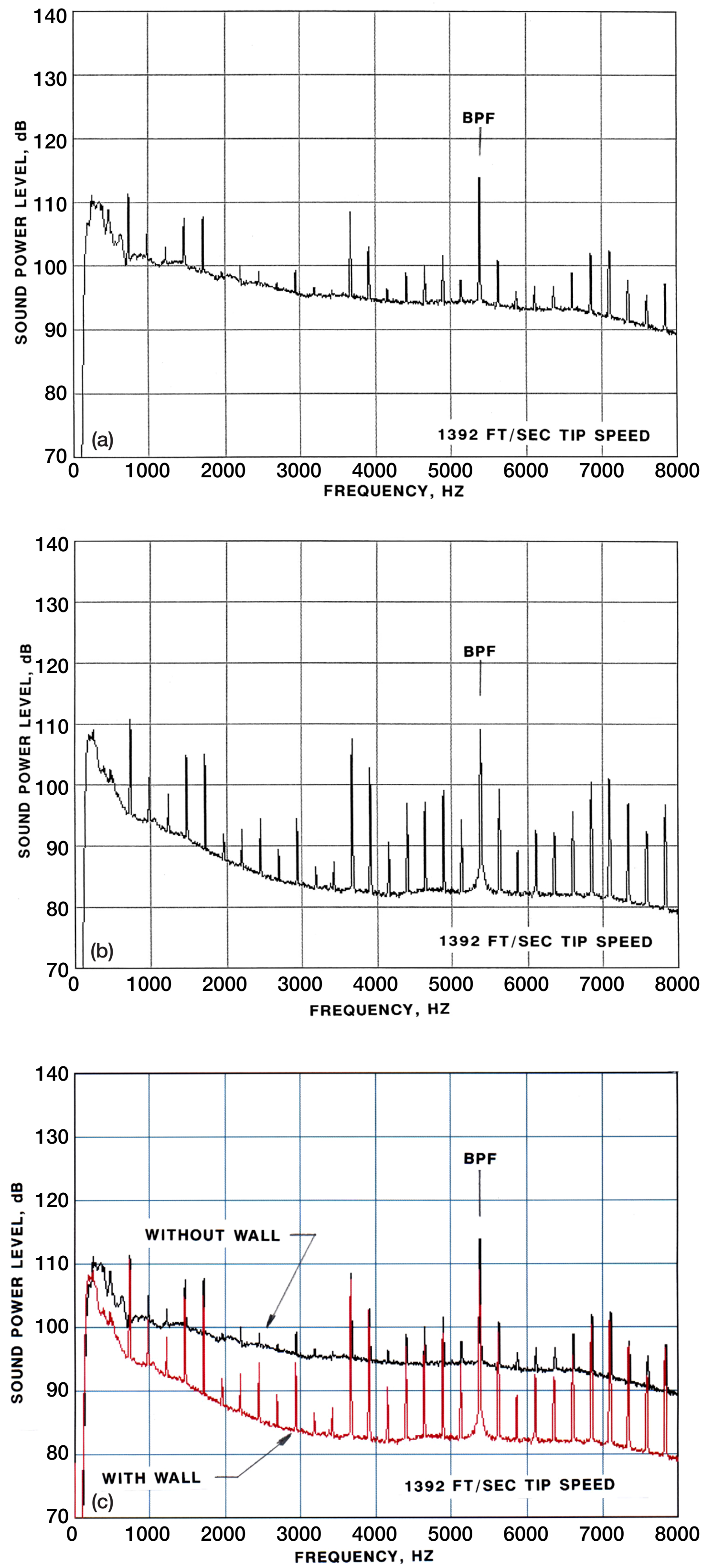

Figure 17.—Sound power lever for 83 degrees and forward. Quiet high-speed fan (a) without wall, (b) with wall, and (c) composite.

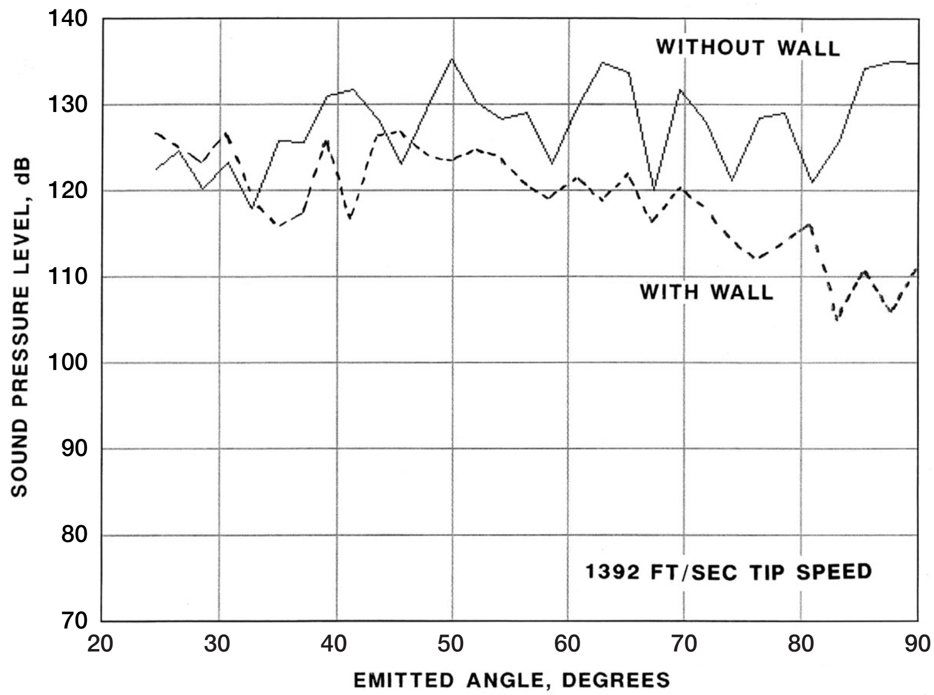

Figure 18.—Blade passing tone variation with angle for baseline fan.

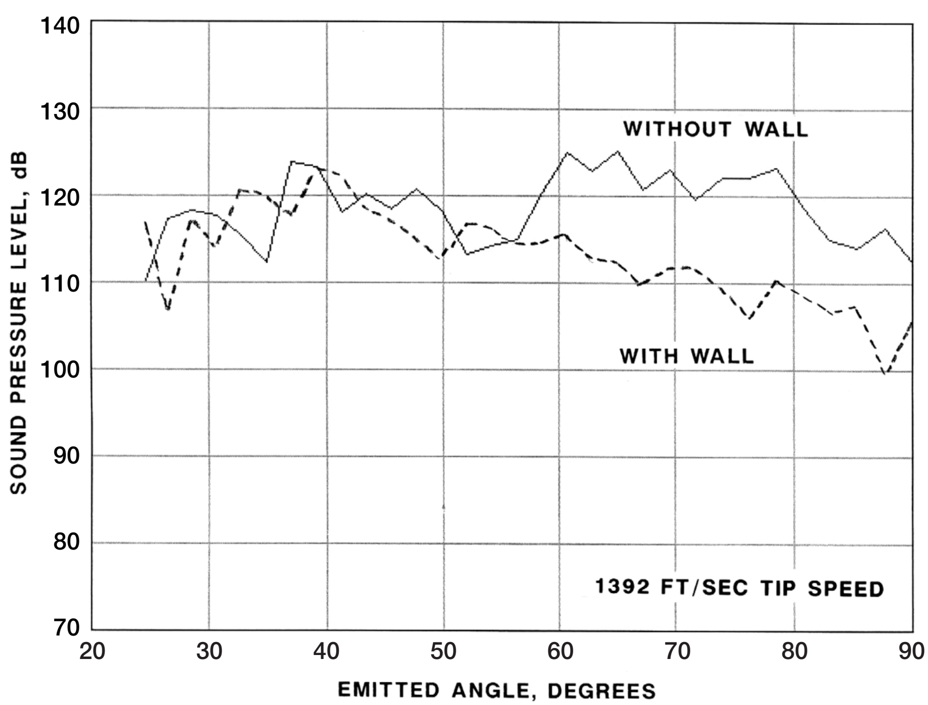

Figure 19.—Blade passing tone variation with angle for quiet high-speed fan.

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13. ABSTRACT ***(Maximum 200 words)***

A forward swept fan, designated the Quiet High Speed Fan (QHSF), was tested in the NASA Glenn 9- by 15-foot Low Speed Wind Tunnel to investigate its noise reduction relative to a baseline fan of the same aerodynamic performance. The objective of the Quiet High Speed Fan was a 6 decibel reduction in the Effective Perceived Noise relative to the baseline fan at the takeoff condition. The intent of the Quiet High Speed Fan design was to provide both a multiple pure tone noise reduction from the forward sweep of the fan rotor and a rotor-stator interaction blade passing tone noise reduction from a leaned stator. The tunnel noise data indicted that the Quiet High Speed Fan was quieter than the baseline fan for a significant portion of the operating line and was 6 dB quieter near the takeoff condition. Although reductions in the multiple pure tones were observed, the vast majority of the EPNdB reduction was a result of the reduction in the blade passing tone and its harmonics. The baseline fan's blade passing tone was dominated by the rotor-strut interaction mechanism. The observed blade passing tone reduction could be the result of either the redesign of the Quiet High Speed Fan Rotor or the redesigned stator. The exact cause of this rotor-strut noise reduction, whether from the rotor or stator redesign, was not discernable from this experiment.

14. SUBJECT TERMS

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